RESEARCH ARTICLE

Investigation of the Effect of window Glazing on the Cooling Loads of Buildings

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ABSTRACT: The cooling loads of a building are also dependent on the amount of heat gained from the outside, and with the need to improve the energy efficiency of buildings in order to reduce energy waste and carbon footprint and ensure access to energy for more people, the right window types have to be utilized. This work used the standard cooling load estimation method to carry out an analytical study of the effects of the U-value and shading coefficient of window glasses on the cooling load of a building under the climatic conditions of Owerri, Nigeria. The results show that increasing the number of window panes from single to double and triple reduced the amount of heat gain into the cooling space. It was also observed that reflective glasses reduce heat gain into the building as opposed to the uncoated glasses predominantly used in Owerri. Also, the presence of argon gas in the space between the panes of the double and triple-glazed windows helped in further reducing the heat gains as against air, which is predominantly used. The reflective double glazing, with an 84.8% reduction in heat gains, showed the greatest reduction as against the uncoated single glazing when considering heat gain through radiation, but the high-performance green-tinted, argon-filled triple-glazed glass showed the greatest reduction in cooling load generally. The study concluded that choosing the right U-value and shading coefficient for windows will help in improving building energy efficiency by reducing energy demand and, by extension, lead to cost savings, reduction of carbon footprint, and achievement of net-zero energy in the built environment.

KEYWORDS: Built environment, Energy, Energy-efficient building, Glazing, Cooling load, shading coefficient

https://doi.org/10.29294/IJASE.10.2.2023.3380-3387

1.0 INTRODUCTION

Energy is the driving force of any economy. It is one of the key fundamentals for the economic development of any nation and all human activities in the 21st century. In Nigeria, energy is the main stay of economic growth and development. Oyedepo [1] explained its significant role in the nation's international diplomacy. He then pointed out that, as a tradable commodity, energy adds to the national income while also serving as a significant input in the nation’s production industry, transport, agriculture, health, and education sectors. Access to efficient energy plays a significant role in improving the quality of life, enhancing educational opportunities, developing small-scale enterprises and gender empowerment [2]. As population increases, the demand for energy also increases. Recently, there has been a very high demand for energy to effectively cater to the ever-increasing global population. Despite the huge investments made in the energy sector since the privatization of the Power Holding Company of Nigeria, PHCN, about 75% of the Nigerian population still lives without access to regular electricity supply [3]. However, the local and global challenge of energy access must be overcome [4]. Therefore, finding more efficient ways to conserve energy and cut down on energy demand and consumption will suffice to ensure energy availability for more people.

Buildings consume about 75% of electricity and account for a significant amount of greenhouse gas (GHG) emissions [5], so energy availability and utilization in buildings require serious attention Akande [6]. In Nigeria alone, the household sector accounts for more than 60%

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Received: 05.09.2023 **Accepted:** 17.10.2023 **Published on**: 25.11.2023

of energy use in buildings [1,7]. Insufficient primary energy makes the situation worse and, inadvertently, has put a lot of strain on individuals in a bid to generate their own power for powering residential homes, office buildings, and business outlets. This has added to emissions and noise from distributed generating sets [7]. Niyi [8] showed that regional surveys suggest that Nigeria's asthma prevalence among adults increased from 5.1–7.5% in 2003 to 13.1–14.2% in 2006, and Nigeria currently has the highest prevalence of asthma in Africa, which is attributed to the exhaust fumes from diesel generators. Though energy is vital for buildings to effectively serve their purposes, Akande [6] warns that if the use of energy in buildings is not properly managed or regulated, it can lead to unnecessary and costly waste for the users and also negatively affect the environment as a result of the continuous release of carbon (iv) oxide. Usman et al., [9] reported that household energy consumption will only increase because of the energy-intensive lifestyle being adopted by people and because of the increase in global temperature. He pointed out lighting, cooling, heating, water pumping, cooking, and entertainment as the key energy consumption services in households. There is therefore a serious need for energy-efficient buildings in order to reduce both energy demand and consumption by these buildings and, in extension, afford more people access to adequate energy.

According to Ochedi et al., [10], energy efficiency involves the use of smaller quantity of energy to achieve results previously achieved with a certain quantity of energy, which means that energy efficient buildings entails using energy in a way that reduces the quantity of energy required to provide building services. They pointed out that energy efficient buildings have been defined as those buildings that apply energy efficient measures to reduce its energy requirements, while making adequate use of available resources. Energy efficient buildings aim at meeting the occupant's need for thermal and visual comfort at reduced levels of energy and resources consumption [9]. Energy efficient buildings offer economic, environmental and social benefits [11].

Windows have been identified as having a significant influence on the energy performance of buildings [12,13]. They are the weakest link in the building when it comes to energy conservation [14,15]. Windows account for 60% of the overall energy loss of a building [16]. This loss emanates from conduction, convection, and radiation, culminating in increased cooling and heating loads in the building [18]. Window glazing is therefore an important factor to consider in passive solar heating and cooling techniques. Ochedi and Taki [10] opined that improvements in the inner comfort of a building can be made while reducing its energy consumption if appropriate window glazing is chosen in consideration of the prevailing climatic conditions. Window glazing have been classified as heat-absorbing glass which transforms solar irradiation to heat and increase the building indoor temperature, preferably used in cold climates; heat-reflecting glass with coatings which hinder the entry of solar radiation into the house, preferably used in hot climates for cooling energy saving; and finally, the low radiation glass with films that tend to reduce the heat transfer coefficient [18]. Tinted glasses enhance energy savings in buildings but reduce daytime lighting significantly [19]. Ochedi and Taki [10] reported 24.91% and 0.59% reductions in the solar annual gains and operative temperature, respectively, by simply using a single leaf with no shading as the glazing template and Single Ref-A-L Tint 6mm as the glazing type. They also noted that the single-leaf tinted glass produced the highest reduction in solar gains. Therefore, the right type of window glazing must be one that balances the need for day lighting with the thermal comfort of the occupants. This is the thrust of the present work, which seeks to establish the best compromise for improving energy efficiency in buildings through the appropriate selection of window materials with an optimum U-value and shading coefficient.

2.0 METHODOLOGY

Owerri, which is the capital city of Imo State with geographical coordinates of 5.4836°N and 7.0333°E, is located in the southern part of Nigeria, where the climatic conditions are mostly equatorial/tropical rain forest. It has an average annual temperature of 25.9°C, which peaks in February at an average temperature of 28.0°C and is lowest in July with an average temperature of 24.2°C. It has a total of about 2412 mm of precipitation per year. The least amount of rainfall occurs in January with an average precipitation of 30mm, while it reaches its peak with an average of 321mm in September. This research used an analytical

method to examine the effect of U-values and the shading coefficient of windows on a typical residential building in Owerri, Nigeria. The plan of the model building is as shown in Fig. 1. Table 1 shows the properties of the windows with the U-value of the single glazing window, while tables 2–5 show the values for the shading coefficient (SC), U-factors, cooling load temperature difference (CLTD), and solar cooling load (SCL), respectively, of the window glasses.

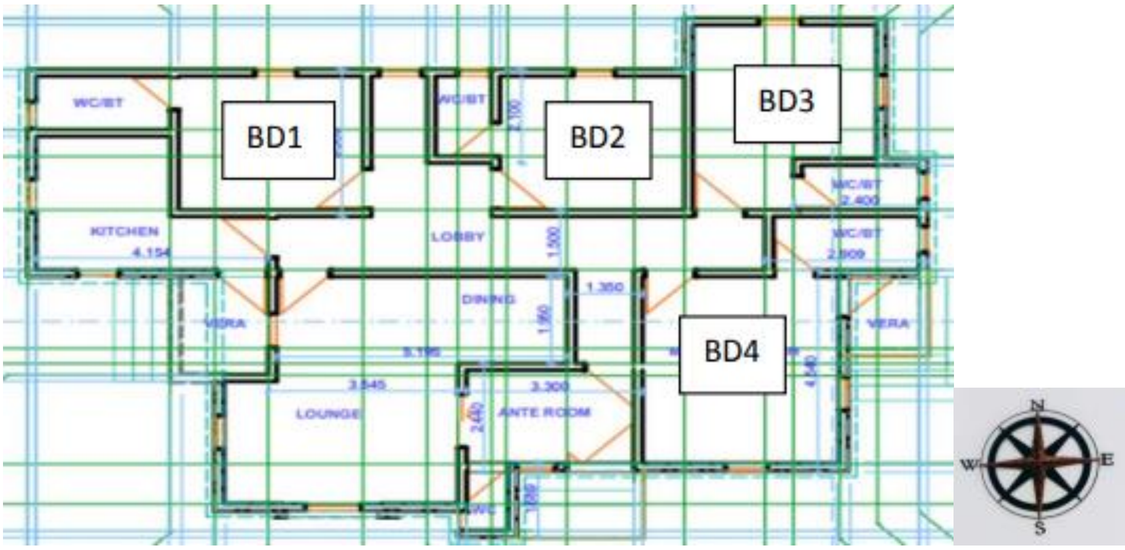

Table 1 Properties of the window

S/N	Zone	Window Type	Dimension(m)	Area (m^2)	U-Value (W/m^2k)
1	BD1, BD2, BD3, BD4, Lounge, Kitchen	double leaf, 6.4mm with aluminum frame and thermal breaks	0.610 × 0.914	0.5575	5.43

The window allows heat into the interior space of the building by conduction and radiation. From [20] and [21], the heat conducted through the window is given as

$$Q = U \times A \times CLTD \quad (1)$$

Where U is the overall heat transfer coefficient of the window glazing, A is the area of the window and CLTD is the cooling load temperature difference.

The radiation heat transfer through the window is given as [21]

$$Q = A \times SC \times SCL \quad (2)$$

Where SC is shading coefficient of the window, which is a measure of the amount of heat gained as a result of solar radiation through the glass. While SCL is the Solar Cooling Factor, which is the rate with which the cooling space absorbs and stores heat.

To examine the impact of glazing and shading coefficient on the cooling load of the building, the window glazing was varied from single glazing to double glazing and triple glazing, while the shading coefficient was alternated between the uncoated and reflective types. The insulation effect of the presence of gas between the panes of the double and triple glazed windows was also investigated, by utilizing both the popular air-filled panes and argon filled panes.

Table 2 The Shading Coefficient (SC) of the glasses [20]

S/N	Type	Description	SC
1	Uncoated Single Glazing	6.4mm clear	0.94
2	Reflective Single Glazing	6.4mm SS on CLR 8%	0.22
3	Uncoated Double Glazing	6.4mm CLR CLR	0.81
4	Reflective Double Glazing	6.4mm SS on CLR 8%, CLR	0.15
5	Uncoated Triple Glazing	6.4mm CLR CLR CLR	0.71
6	Triple Glazing with high performance green tinted glass	6.4mm Hi-P GRN CLR CLR	0.39

Table 3 U-Factors for the windows operable with aluminum frames with thermal break [20]

S/N	Type	Description	U (W/(m²K))
1	Single Glazing	6.4mm	5.43
2	Double Glazing	6.4mm airspace	3.70
3	Double Glazing	6.4mm argon space	3.54
4	Triple Glazing	6.4mm airspace	2.89
5	Triple Glazing	6.4mm argon space	2.73

Table 4 CLTD for conduction through the glass [20]

Solar Time, Hour	CLTD, °C		Solar Time, Hour	CLTD, °C
0100	1		1300	7
0200	0		1400	7
0300	-1		1500	8
0400	-1		1600	8
0500	-1		1700	7
0600	-1		1800	7
0700	-1		1900	6
0800	0		2000	4
0900	1		2100	3
1000	2		2200	2

1100	4		2300	2
1200	5		2400	1

$CLTD_{corrected} = CLTD + (25.5 - t_r) + (t_m - 29.4)$

Where $CLTD_{corrected}$ is the adjusted CLTD for present condition

t_r which is the desired inside temperature = 22°

t_m which is the average daily temperature = 28°

Table 5 Solar Cooling Load (SCL) of glass [20]

Zone Type C

Glass Face	Hour / Solar Time 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
N	16	16	13	13	13	76	72	76	85	95	104	107	110	107	101	91	91	107	44	32	25	22	19	19
NE	22	19	19	16	19	236	334	337	277	192	154	148	142	135	126	113	98	79	50	41	35	32	28	25
E	28	25	25	22	25	261	410	466	457	391	280	195	176	164	148	135	117	95	63	54	47	41	38	35
SE	28	25	22	19	19	142	258	337	381	381	337	258	186	161	148	132	113	91	60	50	44	41	35	32
S	22	22	19	16	16	38	57	72	113	170	221	249	249	221	170	126	104	82	50	41	38	32	28	25
SW	44	38	35	32	28	47	66	82	91	104	113	180	271	347	391	394	350	252	117	88	72	63	54	47
W	54	47	41	38	35	54	69	85	98	107	113	117	186	309	416	482	491	403	158	110	88	76	66	60
NW	38	35	32	28	25	44	63	79	91	101	107	113	113	139	230	321	372	337	123	82	66	54	47	41
Hor	76	66	60	54	50	107	214	337	454	551	627	668	677	652	595	504	387	261	167	139	120	107	95	85

3.0 RESULTS AND DISCUSSION

In Fig. 2, the single-glazing window with a U-value of 5.43, which is the predominantly used window glazing type in Owerri, showed the highest heat gain through conduction when compared to the rest. While the triple glazing with U-values of 2.89 and 2.73 showed the least heat gain through conduction, in the double glazing with U-values of 3.7 and 3.54, the heat transferred through conduction into the indoor space is appreciably higher than the triple but significantly lower than the single glazing. This is as a result of a reduction in the amount of heat eventually reaching the room as it passes through the glasses and the airspace between the glasses; hence, the triple glazing showed lower heat gain than the double glazing, while the double glazing showed a lower heat gain than the single glazing. Also in Fig. 2, differences were also noted in the argon-filled double-glazed and the air-filled double-glazed windows, as well as the argon-filled triple-glazed and the air-filled triple-glazed windows. The argon-filled glass panes reduced the amount of heat load allowed into the living space through conduction; this is a result of the lower thermal conductivity of the argon gas compared to that of air, and hence it minimizes heat transfer. This is in line with the report of studies by European institutes that showed filling the window panes with argon instead of air increases its efficiency by reducing heat gains by about 30% [22].

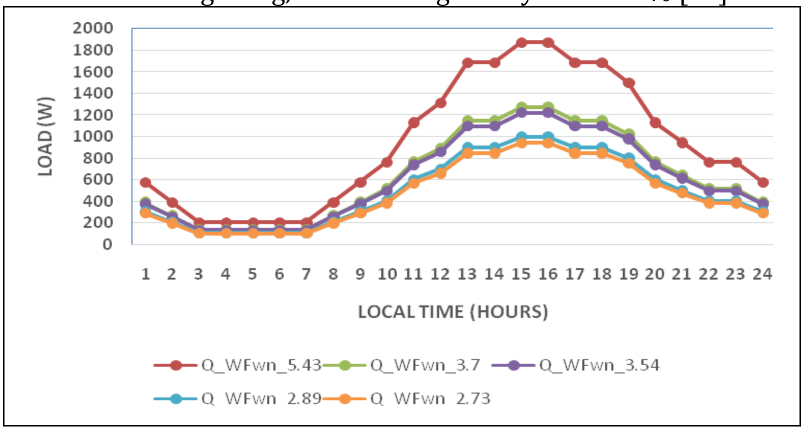

Fig 2 Effect of U-values of different window glazing cooling loads

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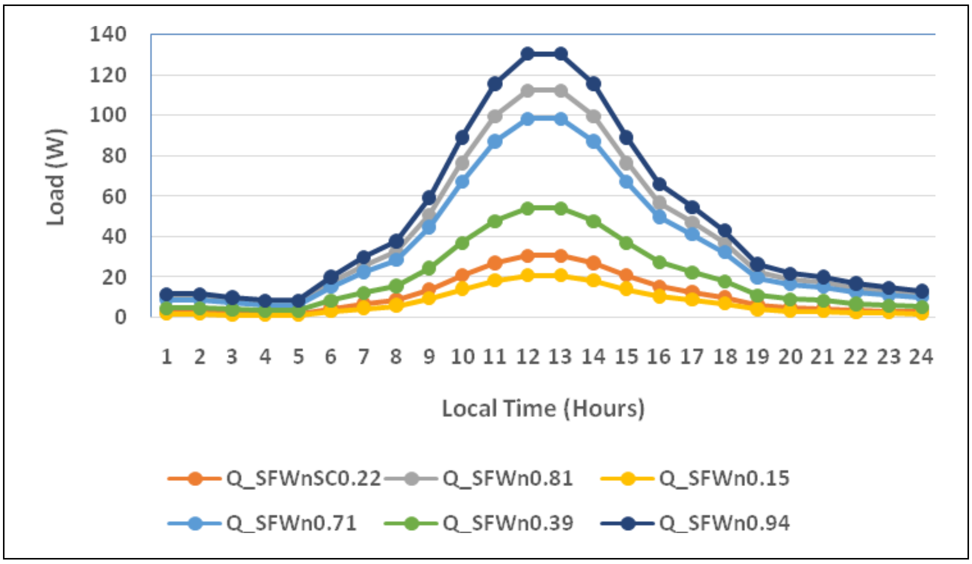

Fig. 3 Effect of the shading coefficient of south facing windows on cooling loads

In Figs 3 and 4, the uncoated single-glazed window, also the predominately used window type in Owerri, showed the highest heat gain through radiation than the rest, for south-facing and west-facing windows, respectively. The differences in the amount of heat gain through the uncoated and reflective glasses of the different window panes are a result of the reflecting properties of the metallic oxides applied to the reflective glasses, which improve their insulating properties, hence reducing the amount of heat gain through them. It can also be seen that, though the heat gain through the uncoated double glazing was found not to be that significant when compared to the uncoated single glazing, the reflective double glazing showed a great reduction in solar heat gains. This is consistent with the findings of [10]. In both orientations of the window, the lower the shading coefficient, the lower the radiative heat loads into the indoor space, and the better the comfort of occupants of such buildings. Even though the peak loads for both orientations occur at different times of the day, it is preferable to position windows south, as it is apparently observed that the peak load of about 130 W occurs a few minutes beyond mid-day, corresponding to the time of peak solar irradiation, while in the west-facing windows the peak load is about 255 W, occurring at about 17:00 hours (5:00 pm).

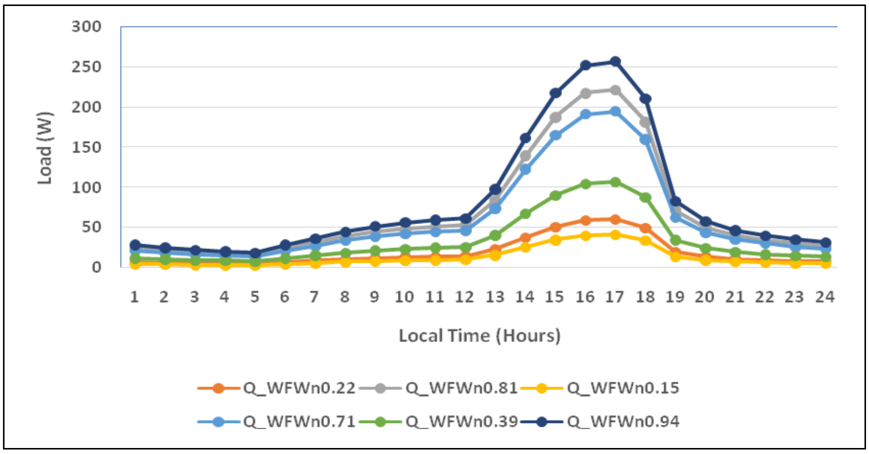

Fig. 4 Effect of the shading coefficient of west facing windows on cooling loads

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Fig. 5 shows the combined effect of U-values and shading coefficients of window glazing panes on the cooling load of indoor space. It is observed that the high-performance green-tinted triple-glazing argon-filled glass showed the greatest reduction in solar heat gain when the combined effect of the shading coefficient and U-value of the windows were considered. This yielded about a 46% reduction in heat gains, which is a significant improvement to the 24.91% reduction reported by [10] when they employed Single Ref-A-L Tint 6mm as the glazing type.

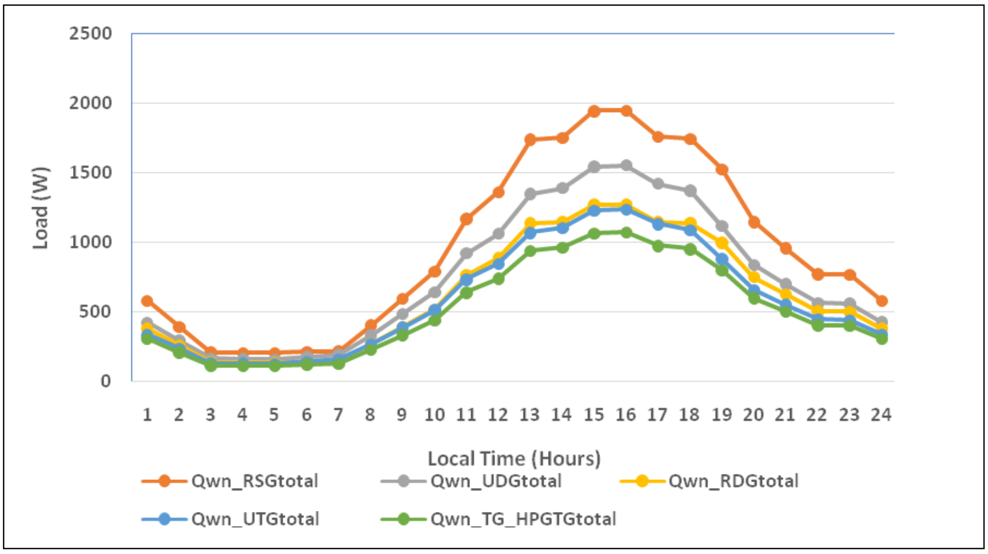

Fig. 5 Combined effect of window glazing and the shading coefficient of windows on cooling loads

CONCLUSION

An investigation of the effects of the U-value and shading coefficient of window glasses on the cooling load of a building under the climatic conditions of Owerri, Nigeria, has been carried out using standard cooling load estimation methods. The findings show that the cooling loads of a building are greatly dependent on the amount of heat gained from the external environment through the windows as well as the orientation of the windows. It has been discovered that the heat gain through the windows in buildings in Owerri can be reduced by using reflective glasses as against the predominant uncoated glasses being used; employing double or triple-glazed windows as against the single-glazed window, which is popular among building developers in Owerri; and adopting argon-filled double or triple panes over their air-filled counterparts, as they offer better insulation. In synopsis, by implementing some passive cooling techniques, the cooling load, space cooling costs, and carbon footprints can be significantly reduced, and occupants overall year-round comfort can be improved.

Acknowledgments

We acknowledge and thank the Applied Energy and Power Research Group, Department of Mechanical Engineering, Faculty of Engineering and Engineering Technology, Federal Polytechnic University of Owerri, Nigeria, for providing analytical tools and other financial support to carry out the work successfully.

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